doi: 10.14355/fiee.2016.05.006

# Influence of Different Corrosive Mediums on Q235 Carbon Steel

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***Abstract***

The corrosion behavior and mechanical properties of Q235 low carbon steel were determined in different corrosive mediums by analyzing the corrosion rate, tensile strength, and microstructure. Various techniques, such as scanning electron microscopy (SEM), and electronic universal tensile testing were used for characterizing the samples. The results revealed that among the various mediums, aerobic bacteria produce the highest degree of corrosion with a large number of corrosion pits on the sample surface and a corrosion rate of 41.36 g/(m2.h) over 10 days. The weight and theoretical tensile strength ($\sigma b$) were clearly reduced with the $\sigma b$ decreasing by 22.4%. The anaerobic bacteria medium, however, produced a less pronounced effect and the sample surface exhibited only slight pitting. The effect of diluted sulfate was even weaker and the surface of the Q235 specimen remained flat without any obvious changes in the mass or size of the sample after 10 days. In the case of diluted sulfate, the mechanical properties were also not significantly affected with $\sigma b$ reducing by only 2.8%. Neither microbial nor diluted sulfate-induced corrosion reduced the elongation of Q235 carbon steel and the fracture surfaces of the tensile samples analyzed by SEM showed characteristics typical of ductile fracture. Similarly, none of the corrosive mediums tested produced hydrogen embrittlement.

***Keywords***

*Q235 Carbon Steel; Microbial Corrosion; Diluted Sulfate Corrosion; Mechanical Properties*

## Introduction

Q235 steel is a commonly used material in engineering machinery, in a variety of architecture and engineering structure applications, and in the manufacture of buildings, high voltage transmission line towers, bridges, vehicles, boiler containers, ships, etc. The mechanical properties of Q235 directly influence the safe use of many engineering structures and components. Q235 steel can undergo corrosion to various degrees when exposed to air, water, and a variety of other mediums, with any subsequent change in its mass, size, or mechanical properties, which directly affects the safety of its use. According to statistics, corrosion caused by bacteria accounts for 20% of the total corrosion damage in metallic building materials [1]. There are more than 10 kinds of specialized phagocytic metal microbial species. Among these, acidithiobacillus ferrooridans and anaerobic sulfate reducing bacteria are two main types. Furthermore, microbial activity on the surface of a biofilm can cause damage through microbially influenced corrosion (MIC). MIC is a phenomenon affecting most commonly used materials.

The microbial bacteria used in this study were extracted from the Fujian Zijin copper mine pit water, which is a leaching solution. Screening by enrichment resulted in aerobic acidithiobacillus ferrooxidans (A.f) and anaerobic sulfate reducing bacteria (SRB). In addition, due to the oxidation of ferrous sulfide, acidophilus bacilli in acidic environment was also used as a medium to investigate the influence of weak acid etching simultaneously with a simple diluted sulfate medium corrosion test. In this study, samples of Q235 steel were subjected to corrosion by aerobic bacteria, anaerobic bacteria, and diluted sulfate. Scanning electron microscopy (SEM), and electronic universal tensile testing were used to analyze the corrosion and mechanical properties and assess the influence of the various corrosive mediums on the mechanical properties of Q235 steel. The corrosion tests used in this study

were carried out strictly under laboratory environment, although the results can be compared with similar research studies.

## Experimental Materials and Methods

### *Experimental Materials*

The material used was a Q235 low carbon steel cut into 20 mm x 20 mm square with a height of 1.5 mm for the corrosion tests, as well as standard tensile samples.

### *Corrosive Medium*

Aerobic bacteria：Acidithiobacillus ferrooxidans (A.f) was cultured in a medium containing $(NH_4)_2SO_4$ (4.3 g/L), KCl (0.14 g/L), $K_2HPO_4$ (0.71 g/L), $MgSO_4 \cdot 7H_2O$ (0.71 g/L, $Ca(NO_3)_2$ (0.014 g/L), and 1000.0 ml of distilled water to yield a final pH of 1.8–2.2. This culture medium was gently agitated for 1 week at 35 °C prior to use.

Anaerobic bacteria: Sulfate reducing bacteria (SRB) were cultured in an anaerobic medium described by Hungate [2]. The culture medium consisted of sodium lactate (3.5 g/L), $NH_4Cl$ ((1.0 g/L), $Na_2SO_4$ (1.0 g/L), $MgSO_4$ (0.1 g/L), $K_2HPO_4$ (0.5 g/L), $(NH_4)_2Fe(SO_4)_2 \cdot 6H_2O$ (0.65 g/L), $CaCl_2$ (0.1 g/L), and 1 L of distilled water to yield a final pH of 7.0–7.2. This culture medium was gently agitated for 1 week at 35 °C prior to use.

Diluted sulfate: pH = 2.0.

Corrosion time: 10 days.

### *Tensile Tests*

The specimens were tested using an electronic universal testing machine in accordance with the GB/T228-2002 standards [3]. Hence, the tensile strength was obtained from three parallel arithmetic averages to determine the influence of microbial and diluted sulfate corrosion.

### *Morphology Analysis*

SEM was used to analyze the tensile fracture surface morphology and microstructure of the Q235 samples after 10 days of corrosion.

## Results and Discussion

### *Influence of the Corrosive Medium on Corrosion Rate*

The corrosion rate of the Q235 samples was determined from their mass before and after corrosion using the following equation.

$$v^{-} = \frac{m_0 - m_1}{S \cdot t} \tag{1}$$

$v^-$ is the corrosion rate in g/(m2.h), $m_0$ and $m_1$ are the masses of the sample before and after corrosion, respectively, in g, S is the sample surface area in $m^2$, and t is the corrosion time in h. Due to the adhering of the loosened corrosion products to the specimen surface, the corrosion products were cleaned from the specimen surfaces using distilled water before weighing.

As seen from Table 1, the A.f medium resulted in a corrosion rate of 41.36 g/(m2.h), which dropped to 19.63 g/(m2.h) and 12.63 g/(m2.h)with SRB and dilute sulfate, respectively. Hence, A.f produced the highest degree of corrosion in Q235 carbon steel.

TABLE 1. MASS LOSS AND CORROSION RATE AFTER 10 DAYS IN DIFFERENT CORROSIVE MEDIUMS

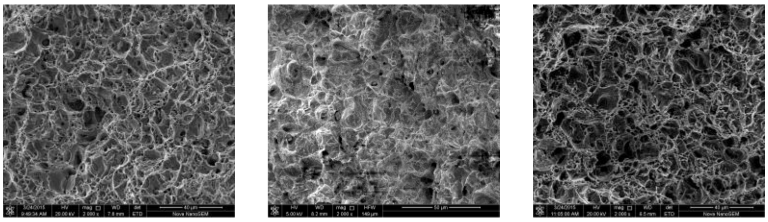
| Corrosive medium | Average mass loss (g) | Corrosion rate (g/(m2.h)) |
|---|---|---|
| A.f | 9.1330 | 41.36 |
| SRB | 4.3333 | 19.63 |
| Diluted sulfate | 2.7881 | 12.63 |

### *Influence of the Corrosive Medium on Mechanical Properties*

In engineering applications, tensile properties are usually the main basis for structural static strength design [3]. The theoretical strength limit was obtained by testing the tensile strength of a blank specimen without corrosion. The theoretical strength limit of Q235 carbon steel ($\sigma b$) is 443.86 MPa. The test results showed that corrosion caused by A.f could reduce $\sigma b$ by 22.4% to 344.49 MPa, while SRB and diluted sulfate reduced the value by 11.3% and 2.8% ($\sigma b$ = 393.71 MPa and 431.58 MPa), respectively.

Elongation is an index of metal plasticity; higher the elongation, the more plastic is the material. A plastic metal can withstand different types of plastic processing, while contributing to safety [3]. Owing to the good plasticity of Q235 steel, the elongation to failure after corrosion remained at around 45% and in comparison to the blank specimen without corrosion, the change was insignificant. Hence, corrosion does not reduce the plasticity of carbon steel.

The SEM images in Fig.1 showed the fracture surfaces of the tensile test samples subjected to corrosion in microbial or diluted sulfate mediums. The fracture surface morphology of the tensile test samples were honeycomb shaped, which was typical to dimple fracture characteristics. Further, many large and deep dimples were observed, which further showed that the materials had maintained good plasticity. From the lack of intergranular fracture characteristics and typical characteristics representing ductile fracture, it was evident that each specimen retained a high degree of toughness, indicating that corrosion with neither microbial nor diluted sulfate medium produced any significant hydrogen embrittlement [4].



(a) (b) (c)

FIG. 1 SEM IMAGES SHOWING THE TENSILE FRACTURE SURFACE MORPHOLOGY OF CARBON STEEL AFTER EXPOSURE TO (A) DILUTE SULFATE, (B) ANAEROBIC BACTERIA, AND (C) AEROBIC BACTERIA

### *Influence of the Corrosive Medium on the Sample Microstructure and Composition*

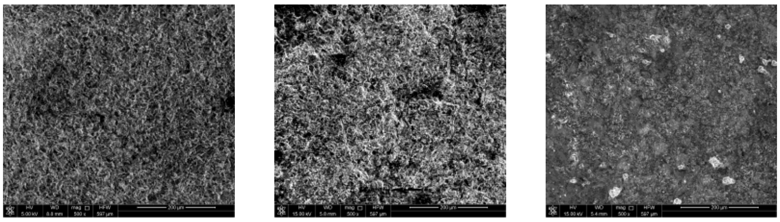
The photographs in Fig. 2 and SEM images in Fig. 3 indicate the macroscopic and microscopic morphologies of Q235 carbon steel exposed to the three corrosive mediums, respectively. Fig. 2 showed that the specimen surface exposed to diluted sulfate was smooth, indicating only mild corrosion because diluted sulfate is a non-oxidizing acid, which leads to electrochemical corrosion accompanied by hydrogen evolution. The corrosion of carbon steel by this mechanism is mainly dependent on the depolarization of hydrogen ions.

(a) (b) (c)

FIG. 2 PHOTOGRAPHS SHOWING THE MACROSCOPIC MORPHOLOGY OF Q235 CARBON STEEL AFTER BEING CORRODED BY (A) DILUTE SULFATE, (B) ANAEROBIC BACTERIA, AND (C) AEROBIC BACTERIA

The specimen surface exposed to the anaerobic SRB medium showed slight pitting, which is attributed to the formation of a biofilm required to maintain a localized anaerobic environment. This pitting became more pronounced on the surface of the specimen exposed to aerobic A.f, because in this case, the occurrence of corrosion relies on the existence of an extracellular polymer, which allows bacterial cells and their metabolites to bond to each other. This results in the bacteria selectively breeding in specific areas on the surface, causing an uneven distribution of the biological membrane. A soaking experiment indicated that the surface of the sample corroded

by A.f was covered by a relatively dense layer of the corrosion product after 10 days and the early corrosion substrate surfaces generated by these corrosion products created localized areas of increased oxygen concentration.



(a) (b) (c)

FIG. 3 SEM IMAGES SHOWING THE MORPHOLOGY OF Q235 CARBON STEEL AFTER SUBJECTED TO CORROSION BY (A) DILUTE SULFATE, (B) ANAEROBIC BACTERIA, AND (C) AEROBIC BACTERIA

## Conclusions

Both microbial and diluted sulfate corrosion media were capable of corroding Q235 steel, although the degree and mechanism of corrosion were different. The conclusions of our study were listed below.

(1) Aerobic bacteria exerted the maximum influence in terms of corrosion, producing a large number of corrosion pits, leading to a 10-day corrosion rate of 41.36 g/(m2.h), which reduced the σb by 22.4%.

(2) Anaerobic bacteria were less effective as a corrosion medium, causing only slight pitting.

(3) Diluted sulfate showed a weak corrosion effect, leaving a flat sample surface without any significant changes in the mass, size, or tensile strength. The σb was reduced by only 2.8%. Therefore, the strong corrosion caused by the A.f medium on Q235 carbon steel can mainly be attributed to the bacteria.

(4) Neither microbial nor diluted sulfate corrosion reduced the elongation of carbon steel and any evidence of hydrogen embrittlement or loss of plasticity was absent.

Currently, to the best of our knowledge, there are not many effective measures to control microbiological corrosion. Our study on microbial corrosion is an initial demonstration of the regularity and mechanism of corrosion, which can be used for improving corrosion control and ensuring safety to reduce economic losses.

### ACKNOWLEDGMENTS

I would like to express my gratitude to all those who helped me during the writing of this thesis. I gratefully acknowledge the help of my colleague, Ms. Hongqian Chen, and Dr. Xingyu Liu, who had offered me valuable suggestions in this study. At the same time, I would like to thank all the literature author.

### REFERENCES

[1] Jinyi W., Ke C. Biological corrosion and protection of materials. Chin. Metallurgical Industry Press. (2012).

[2] Xiuli H., Zhilan L. Modern microbiology and experiment technology. Chin. Science Press. (2000).

[3] Mingfang L., Shengxin L. Metal material mechanical properties of the manual. Chin. Machine Press. (2011).

[4] Weilong X., Ke C., Yuhui Y., et al. Effect of microbe on the corrosion behaviors and mechanical properties of 25 carbon steel in tropical seawater condition. J. Chin. Soc. Corros. Prot. 30:359-363. (2010).

[5] Little B., Wagner P. Myths related to microbiologically influenced corrosion. Mater. Perform. 36:40-44. (1997).

[6] Xu C. M., Zhang Y. S., Cheng G. X., et al. Investigation of sulfate-reducing bacteria on pitting of 316L stainless steel in cooling water system for oil refinery. J. Chin. Soc. Corros. Prot. 27:48-53. (2007).

[7] Starosvetsky J., Starosvetsky D., Armon R. Identification of microbiologically influenced corrosion (MIC) in industrial equipment failures. Eng. Fail. Ana. 14:1500-1504. (2007).

[8] De Brito L. V., Coutinho R., Eduardo Cavalcanti E. H, et al. The influence of macrofouling on the corrosion behaviour of API 5L X65 carbon steel. Biog. 23:193-201. (2007).

[9] Goecke F., Labes A., Wiese J., et al. Chemical interactions between marine macroalgae and bacteria. Mar. Ecology-process Ser. 409:267-299. (2010).

[10] Trouillon R., Combs Z., Patel B. A., et al. Comparative study of the effect of various electrode membranes on biofouling and electrochemical measurements. Elec. Communications. 11:1409-1413. (2009).